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The future role of virtual and physical modelling in industrial design

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Abstract
Three-dimensional (3D) modelling is recognised as an essential aspect of industrial design activity. However, computer technologies are beginning to change the nature of these models. This paper explores the role of conventional and computer-based 3D models as used by the industrial design profession within programmes of new product development (NPD). There is seen to be an incompatibility between the physical models needed by the marketing and industrial design stages of NPD and the virtual models which are the foundation of any computer-based system. The paper suggests that the emerging technologies of rapid prototyping may offer solutions to these difficulties and extend the sophistication of the industrial design model.

Introduction
In undertaking projects that require the manipulation of complex three-dimensional (3D) forms, industrial designers employ many techniques to originate, develop, evaluate and present their ideas. In recent years, a key challenge to the computing industry has been to integrate the use of ‘virtual’ computer-based models into a profession where physical models have conventionally played an essential role in defining product form.

In identifying how successful this integration has been, this paper will explore the use, relevance and opportunities for physical and virtual 3D models within the industrial design profession, and indicate how conflicting patterns of use may be resolved using the emerging technology of rapid prototyping.

No two programmes of new product development (NPD) can ever be seen as identical in terms of the way modelling is used by industrial designers. However, a general pattern of project management can be identified to illustrate the relationship between conventional two-dimensional (2D) and three-dimensional physical modelling techniques. This generally involves the production of 2D sketches for the rapid generation of ideas; 3D ‘sketch models’\(^1\) for a more detailed manipulation of form; 2D renderings to present the proposal(s) to a client; 3D block model(s) as an exact representation of the proposal; 3D prototypes to define internal detail and undertake performance testing.

As this paper is to focus on the role and function of 3D models, a brief indication of how and why they are used must be made.

Physical industrial design models
As industrial designers often find themselves manipulating complex three-dimensional forms, the ease and spontaneity of sketching need not be restricted to a 2D paper-based format. Where form and the relationships between surfaces need to be more explicitly expressed and developed, it is common practice to engage in 3D sketching, commonly referred to as sketch modelling.

The designer may use 2D sketches as a guide when undertaking sketch modelling, but the technique is particularly suited to interactive design development, where the designer handworks the form until content with its look and feel. Whilst maintaining an acknowledgement of the technical criteria on which the product is based, sketch modelling has a strong association with sculpting.

2D renderings offer a cost-effective way of providing a client with an indication of design intent, but as a 2D medium they are incapable of giving a client sufficient confidence in a proposal to proceed directly to tooling. It is therefore standard practice to produce a block model as an accurate 3D representation of what the product will look like. Block models rarely have any working features due to the fabrication techniques employed in their construction.

Whilst essentially being produced for the client, the industrial designer will make subtle design decisions as the block model is produced. These are necessary due to the complexity of product forms where surfaces do not always turn out as originally intended. By actually undertaking or closely overseeing block model production, the industrial designer can maintain the interactive inputs necessary to ensure a successful outcome.
Although important to an entire NPD team, the marketeer is particularly interested in the block model. The marketing profession has the greatest appreciation of competitive products, what the consumer requires, as well as responsibility for brand positioning and promotion. The marketeer must therefore be content that the industrial design solution will be an attractive proposition to the customer.

Block models are generally seen as the conclusion of an industrial design input as they accurately define the product form and use. On presentation and ‘sign-off’ (acceptance) of the block model the industrial design input decreases dramatically. Subsequent support tends to be in fine detailing and production support. Detailed tooling drawings that specify internal detail can be produced by taking the industrial designer’s layout drawings or by transposing dimensions directly from the model. In effect, the product is redrawn in greater detail by a third party.

To ensure that the design proposal performs as required, a manufacturer would conclude a test programme by producing prototypes that were not only fully functional but visually accurate. As these prototypes integrate both visual and engineering detail, their production cost is considerably greater than that of the block model. They also take considerable time to produce, which is often a cause of frustration when they are required to complete a testing programme so that production and marketing promotion may commence.

Having defined how conventional 3D modelling is undertaken by industrial designers, the use of virtual 3D models will now be investigated.

Virtual industrial design models

Computer aided industrial design (CAID) is the activity of 3D modelling for industrial design purposes that utilises specialised computer hardware and software technology. The design profession, particularly in the graphic design area, has been making productive use of computer technology for at least a decade. The ability for computers and the graphical applications running on them to easily and quickly create and manipulate images and text has attracted designers since they were developed. 2D computer modelling developed into 3D modelling and software products have been created specifically for the industrial designer which enable the modelling, manipulation and visualisation of 3D forms within the computer environment. These products are referred to as CAID applications.

All 3D computer modelling generates digital product models; they exist exclusively within the system made up of the computer hardware and modelling application i.e. the computer environment. These digital models do not have any physical presence and are referred to in this paper as ‘virtual’ models. Thus, CAID applications generate virtual industrial design models.

CAID applications such as Swivel 3D have been used for five years to present product proposals to clients in the form of 2D images, either still or animated. CAID applications similar to Swivel 3D cost less than £1000 and can run on inexpensive desktop personal computers such as the Apple Macintosh II family. The industrial designer manipulates virtual 3D forms, via the computer screen and input devices such as keyboard and mouse, to create the final desired form. Rendering applications can then be used to visualise these models as realistic 2D images which can be used for communication and evaluation in the same way that conventional physical 2D rendering is used. This usage is common for all CAID applications, from the lower cost products like Swivel 3D to the more recent, highly sophisticated and more expensive products such as Alias Studio, Evans & Sutherland CDRS and DeskArtes. These latter products need powerful workstation computers and with this hardware can cost £20,000 to £100,000 for one system. They are different from advanced computer aided engineering (CAE) applications in that their modelling methods and other facilities such as advanced visualisation capabilities have been tailored to the perceived needs of industrial designers.

This generation of CAID products is setting out to be the future primary modelling tool for the industrial designer. Their speed and sophistication of modelling and visualisation allows the industrial designer to quickly and effectively model design proposals and communicate them to their clients. In this sense they are essentially improvements on products like Swivel 3D. The virtual models created on all of these systems are used by industrial designers to generate visualisations, i.e. 2D virtual or 2D physical models. The most important difference is that the 3D virtual models created on these new CAID applications can be fully utilised by the design functions that precede and follow industrial design in new product development programmes of manufacturing industries.

Despite the wide range of applications for CAID systems fundamental differences do exist. The most important of these concerns how the computer and CAID application have created the model, i.e. the
Advanced CAID applications generate different virtual models that are of more value because they can be directly utilised by other design functions. These high-level CAID virtual models are created within the computer environment in a more mathematically complete sense than the low-level CAID models. Industrial NPD processes which utilise computer technology for much of the design, development and manufacturing stages, employing advanced computer aided engineering and computer aided manufacturing (CAM) applications can make full use of a high-level CAID model. Low-level CAID models cannot be used by these advanced CAE and CAM applications and thus their value in NPD is reduced.

CAE and CAM applications are the basis for a computer-based NPD programme where the product being developed is in the form of a virtual digital model. This type of model can be shared by any number of people, anywhere and at any time, in stark contrast to a 3D physical development model. Thus design work can be carried out concurrently rather than sequentially. Such a concurrent approach can provide massive commercial advantage to a company as the time taken to bring a new product to the market place can be significantly reduced i.e. shortening NPD time. The virtual model will thus become increasingly important for industry and industrial designers will have to take account of this.

The advanced CAID applications will support industrial designers in an attempt to better integrate with industries' computer-based NPD processes. The ideal is that the industrial designer will use the CAID application as the primary modelling tool at the beginning of the NPD process. These models will be used to generate the visualisations of the designs in still or animated form. The benefits of this approach then appear when the industrial design models are handed over to the client and the other design and development disciplines. Conventional physical models, 2D or 3D, have to be translated into the type of model preferred by the company's NPD process, a 3D virtual model if the company uses CAE/CAM procedures. There will be a saving in time and resources if the industrial designer can hand over a virtual model that can be directly used by the manufacturer for further design, development and production. There is also the potential for integrating the industrial design activity into the concurrent engineering process. Industrial design activity may be able to overlap with other design activities with the virtual model being worked on concurrently by industrial designers and engineers. Virtual industrial design models will be used more extensively as professional industrial design work is carried out globally and designers can work collaboratively but remotely using networked computer systems.

The implication of using an NPD programme based on the use of digital models is that there is no requirement to have a physical model, a real solid object of some form, during the design and development of a new product. Yet we have made the point that physical models have a crucial part to play in industrial design activity, when the marketing function of a company is preparing to authorise further design, development and production work.

There is thus seen to be an incompatibility between the physical models needed by the marketing and industrial design stages of a traditional NPD process and the digital product models used by future computer-based NPD systems.

High-level 3D CAID applications have a significant role to play in the improved integration of industrial design in a computer-based NPD system. This is not only because the computer models created by these applications can be used for further design and development within those systems but also because they will be able to support a development in modelling which may provide a solution to the problems which surround the mismatch between the physical and virtual model. This solution is known as rapid prototyping.

Rapid Prototyping

The new technologies of rapid prototyping (RP) are offering the possibilities of generating physical models quickly from a virtual computer model at any stage in the NPD process. Compared to other methods of generating physical models, such as using a traditional computer numerically controlled (CNC) machine to cut the form from solid material, RP is quick and relatively straightforward.

As rapid prototyping techniques are in their infancy, relatively few techniques are commercially available.
Currently the principal processes are: stereolithography, laminated object manufacture, fused deposition modelling, selective laser sintering, and solid ground curing. All the techniques require a completed 3D digital product model which is translated into a datafile that the various RP machines can understand.

As stereolithography is currently the most established and widely used rapid prototyping technique, this will be defined in some detail to indicate the nature of the underlying technology.

The basic principle of stereolithography involves the hardening of a photosensitive polymer resin by an ultraviolet light source that is generated by a precisely focused laser, its position controlled from the digital model data. The equipment used to carry out this process incorporates a vat of liquid polymer in which is suspended a table that can move vertically. The laser light is projected onto the surface of the polymer from above. Prototype models are built up in layers by hardening layers of polymer from the base of the model upwards. When a layer has been created the table moves down (typically 0.13mm) and another layer is hardened. Slowly, as the table descends into the vat, the model builds up into the component as displayed on the computer screen. When the model is completed it can be removed from the table, any residual resin is removed using an alcohol based solvent.

The next operation is to fully harden the polymer by placing the model in an ultraviolet oven. This final hardening is undertaken as the laser only achieves 95% curing to prevent internal stresses being set up and distorting the form.

The surface finish of these models is dependent on the depth of each step of the table. To reduce the production time the step size can be increased, but the surface finish is more faceted. Similarly the step size can be reduced to produce more layers and hence a smoother finish, but this increases the production time and therefore unit cost. If necessary, the faceted surface can be flattened by a light shot blasting followed by the application of a spray based filler. If required for visual prototypes, the model can be finished with automotive paint using techniques identical to those used in ‘block modelling’.

Stereolithography is principally used by the automotive and aerospace industry for the production of complex forms. Applications include fit and function assessment and use as master patterns to produce cast components in a material that is more representative of the production item.

The latter makes it possible to economically represent an injection moulding prior to the commissioning of tooling.

Due to the relatively high level of investment required to purchase a stereolithography machine, model production tends to operate as a bureau service. For a machine capable of producing a component up to 508mm x 508mm x 610mm, the price is currently around £350,000. In addition there is an annual maintenance budget of approximately £25,000.

Case Study

The authors have investigated the use of stereolithography within industrial design activity. This was with the aim of establishing potential links between the virtual and physical model and suggesting ways that CAID can be better integrated within the established procedures of industrial design.

Companies manufacturing ceramic tableware use industrial or ceramic designers to generate new product concepts at the start of an NPD programme. These designers have traditionally designed and modelled using conventional manual techniques such as sketches, renderings and 3D physical appearance models.

The high level CAID application DeskArtes was originally developed for the ceramic industry in Finland. Its computer modelling methods allow the easy creation of the complex forms of ceramic tableware. DeskArtes was used to model ceramic tableware products for a company in Stoke-on-Trent, UK. These models were rendered using DeskArtes to create photorealistic images of the proposed designs. The computer images were of a very high quality, with qualities such as reflection, cast shadows and mapped surface patterns. These 2D models could be either viewed on screen or reproduced with a dye sublimation printer to allow choices to be made by the marketing function of the company.

At this point in the industrial design programme intermediate choices are commonly made based on 2D work whilst final decisions on which individual pieces will go on to production are made only after 3D physical models have been created. It is normal practice for 3D solid physical models of the ceramic pieces to be created in-house by skilled ceramic modellers using plaster of Paris. Rapid prototyping was used to bridge the gap between the 3D virtual and the 3D physical model. One of the products created using DeskArtes, a coffee pot with complex
fluting, was chosen and the virtual model was used to create a physical model using the stereolithography/RP process described above. This model was finished by hand using conventional industrial design model finishing techniques so that the model looked identical to a real piece of ceramic tableware.

A finished stereolithography model of ceramic tableware such as the coffee pot is a remarkable simulation of a piece made from china. As well as being virtually identical in appearance, it has similar weight and balance characteristics and can function as a pot to pour liquid. This physical model can be used for complete marketing evaluation. This would not be possible with the conventional physical model created at this stage of NPD in the ceramic industry. The finished stereolithography model can also be used as a primary tool for the production of the final pieces of china as block moulds for slip casting moulds can be taken.

The CAID programme for the design and modelling of the coffee pot was no longer than the conventional design route. It provided all the model types necessary for the designer and the company, with stereolithography being a crucial enabling technology when a physical model was required. The major benefit of using digital product models in the industrial design process is that the company could use those models directly to generate tooling for the production items. This represents a significant saving in time which should translate into commercial advantage.

Conclusions

The paper has investigated one aspect of the issues that surround the use of computer technology for industrial design activity. Those issues concern the types of models to be used by the various design and development functions within programmes of new product development. There is perceived to be a mismatch between the virtual or digital product model which is the basis for computer based NPD systems and the physical model which is recognised as necessary at some point in the industrial design stage of NPD, whether CAID is used or not.

The authors consider that the developing technologies of rapid prototyping will have a significant role to play in the changes that will be necessary if the innovative technology of CAID is to be successfully adopted by the industrial design profession.

There are other issues of concern to the industrial design profession when investigating the use of CAID. These include procedural issues such as identifying how best to mix the most successful CAID practice with conventional modelling practices of industrial design to achieve the correct balance between commercial advantage to the manufacturers and the design qualities of the final product. Managing the inevitable changes that go along with implementing new technologies is also an area worthy of investigation. The financial and other costs involved in adopting high-level CAID applications are also highly significant.

There is the opportunity, if the above issues can be satisfactorily resolved, for virtual models to extend the role of the industrial design model and for industrial designers to be better integrated into future systems of product design and manufacture. This can only be advantageous to the industrial design profession, manufacturing industries and ultimately to the products of the future.

Research is required in this area of industrial design and manufacturing to address these and other issues.

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